INVESTIGATION ON HYBRID CONTROL OF PARALLEL MULTIPHASE DC-DC CONVERTER FOR WELDING APPLICATION

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Abstract: *This work focuses on the enactment of Adaptive hybrid controller with parallel multi phasing DC- DC converter intended for direct current (DC) Arc welding application. In this regard Parallel multi phasing concept applied for various types of DC- DC converter like BUCK fed BUCK, BUCK fed SEPIC and BUCK fed CUK are compared and best performed topology BUCK fed CUK is considered. The controller for proposed converter topology adapts based on the control action required with initial fuzzy controller for better dynamic changes and finial desired minimum steady state error with PI controller. A complete comprehensive simulation of proposed controller is carried out and results indicate the dynamics of proposed system is robust with sudden variations in load with adaptive hybrid controller in high current DC welding application.*

Keywords *- DC Arc welding, Fuzzy logic Controller, Hybrid controller, Parallel converter, PI controller*

1. Introduction

The power source of welding decides, all the required attributes and the grade of welding [1, 2]. The welding power supply with DC output provides high stability [3]. Conventional dc welding sources apply control action on inverter side and no control on input rectification part with high value input capacitor which is not economic [3]. To improve the input power quality front end converter topology has been proposed in [3]. Detailed analysis of literature highlight the merits of DC-DC converter for high current welding applications [4].

Parallel operated DC to DC converter have several advantages like low stress on semiconductor devices, reliable, high current carrying ability and good thermal conductivity. Researchers have explored the use of coupled inductor for parallel connected Single-Ended Primary Inductor Converter (SEPIC) topology [5]. In [6] importance of parallel-series topology operated under resonant on input side is explained. It is in this perspective this work focuses on parallel multi-stage converters for welding applications. The controller design is vital for ensuring desired operation of the power converter. A two-loop arrangement take in over current preventive and controlled DC voltage. An investigation carried out with small-signal analysis for proposed converter system is discussed in [7]. The fault tolerant capability of parallel converters and their merits are discussed in detail in [8, 9]. A several-sliding-surface and integral-variable-structure concept incorporation results in improving ruggedness control is explained in [10]. The adaptive control of proposed converter with uncertain parameter is discussed in [11]. Bifurcation behavior in parallel-connected buck converter to enable stable current sharing is explained in [12, 13]. In [14] the implementation of PID and fuzzy logic controller for DC-DC buck converter using digital signal processor is explained. A new different modulator for parallel converter that combines intersperse and spread-spectrum concept in order to reduce conducted EMI originated.The design of fuzzy controller to reduce the current ripples. Control method for equal current sharing with linear and nonlinear load for three-phase parallel converter. An intensive investigation of various reference acknowledge that response of a system at various stage depend on control action. PI is better for steady state and for transient it is to go with intelligent controller(FUZZY). In this context an adaptive switching methodology is discussed for Parallel multi-stage BUCK fed CUK Converter.

2. Characterization of BUCK Fed CUK Converter

A. Modes of BUCK Fed CUK Converter

Parallel BUCK fed CUK converter block diagram is shown in Figure.1 where output of first converter is given to second converter. Therefore, two stage voltage reduction take place and range of controllable duty radio will increase. Voltage stress on IGBT under turn off condition reduces. Since BUCK fed CUK converter are connected in parallel entire load current get divided into number of parallel stage. Paralleling of converter will reduce current crowing under turn on condition and thermal stress.

The BUCK fed CUK converter consists of two IGBT named S1 and S2, two fast recovery diode D1andD2 used as freewheeling action when corresponding IGBT is in turn off condition. L1 C1 and L2,L3,C2,C3 are corresponding inductor and capacitor of stage1 and stage2 respectively which is shown in Figure.2. There are five modes of operation under continuous conduction mode. For proposed converter Various modes of operation are diagrammatically explained from Figure.3 to Figure.7.

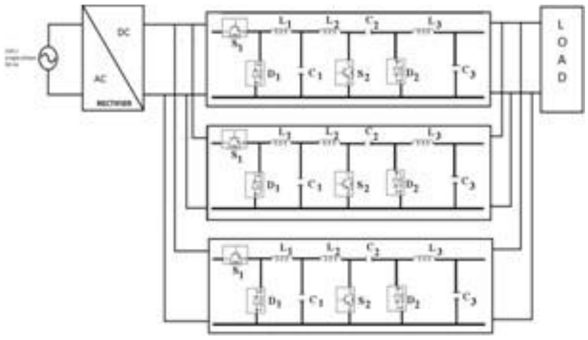


Figure 1. Block diagram of the parallel BUCK fed CUK converter

Mode I: In this mode source is disconnected from load since both the switch S1 and S2 is in off state, only stored charge in L3 will circulate through to load via Diode D2,

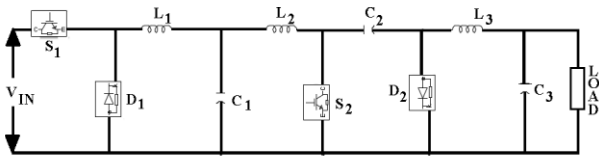
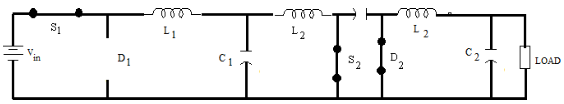


Figure 2. BUCK fed CUK converter

inductor L1 and L2 are charged is given by the equation.1 and equation.2.



$$VL1 = VIN - VC1 \quad (1)$$

$$VL2 = VC1 - VC2 \quad (2)$$

Figure 3. . Mode-I

Mode II: In this mode C2 get charged for Vin which in turn discharge through inductor L3 this happen due to Switching state of S1 is ON and S2 is OFF.

$$VL2 = -VC1 \quad (3)$$

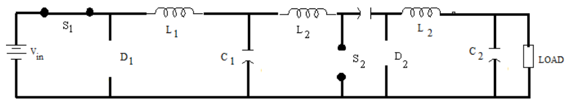
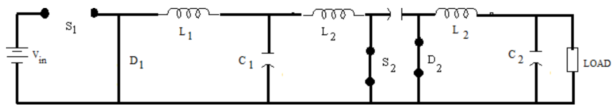


Figure 4. Mode-II

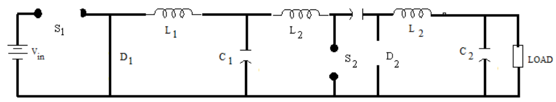
Mode III: This mode is extension of mode II, the inductor L3 continuous to discharge through load



since both the switch are OFF.

Figure 5. Mode -III

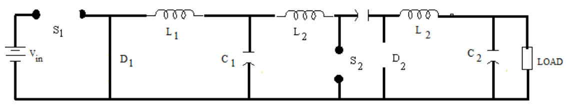
Mode IV: In this mode Capacitor C3 get charged from stored charge of inductor L2, which supplies



the load switch S2 is ON and S1 remained OFF.

Figure 6. Mode -IV

Mode V: This mode is repetition of mode-III. Source is present to load only in mode-II. All mode of proposed converter is to operate in system in step



down operation.

Figure 7. Mode-V

B. Analysis of BUCK and CUK Converter

A two stage step down was carried out with different converter topology like BUCK fed BUCK, BUCK fed SEPIC and BUCK fed CUK. Among three topology the performance of BUCK fed CUK was better which is shown in table. 1. In the proposed topology BUCK converter is operated on closed since the entire range of duty cycle buck is possible and CUK converter operated on output side to have minimum current ripple.

The design equation of buck converter are as follows

Vin =input voltage

D= Duty ratio

fsw = Switching frequency

Tp = total time period

Vc1 = buck converter output voltage

The output voltage of buck converter depends on duty cycle which is given in equation.3.

$$Vc1 = 1/D(Vin) \tag{3}$$

The minimum inductor value required to operate converter in continuous conduction mode(CCM) is give equation.4.

$$L1 = \left\{\frac{Vout}{\Delta I * fsw * Vin}\right\}(Vin - Vc1) \tag{4}$$

The minimum capacitor vale required to operate in CCM is shown in equation.5.

$$C1 = \{\frac{\Delta Il}{8 * fsw * \Delta Vc1}\} \tag{5}$$

The peak ripple current is most important parameter in designing a converter and this parameter depend on inductor value shown in equation.6

$$\Delta I1 = \left\{\frac{D}{fsw * L1}\right\}(Vin - Vc1) \tag{6}$$

The design equation of CUK converter output voltage are as follows and converter duty cycle is operated between 0 to 50% as we operate only in buck mode.

$$Vout = -Vc1\{\frac{D}{1-D}\} \tag{7}$$

The minimum inductor value required to operate CUK converter in continuous conduction mode(CCM) is give equation.8

$$L2 = \left(\frac{R}{2fsw}\right)\{\frac{(1-D)(1-D)}{D}\} \tag{8}$$

$$L3 = \left(\frac{R}{2fsw}\right)\{1 - D\} \tag{9}$$

The minimum capacitor vale required to operate CUK converter in CCM is shown in equation.10 and 11

$$C2 = (1/2fswD)\{D\} \tag{10}$$

$$C3 = (1/8fswD)\{D\} \tag{11}$$

The peak ripple current required on output depends on equaction12 and 13

$$\Delta I2 = (D * Tp)\{\frac{Vin}{L1}\} \tag{12}$$

$$\Delta I3 = (\Delta Tp)\{\frac{Vin}{L2}\} \tag{13}$$

With all this equation proposed converter is designed and their performance are evaluated on result and discussion.

3.Adaptive Hybrid Controller for Proposed Converter

This section contemplates the need of Adaptive hybrid pro- portional–integral fuzzy controller for welding application combinatorial the advantages fuzzy controller when system change from one steady state to another steady state and PI controller when change in error is small . The block diagram of Adaptive controller has been represented in Figure 8. A simple switching method is implemented which Switch from one controller to another controller based on the error voltage value. The current voltage error (e) and previous voltage error (ce) are used by the fuzzy logic controller to divided into seven linguistic variables for input and output : Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), and Positive Big (PB) shown in table.1

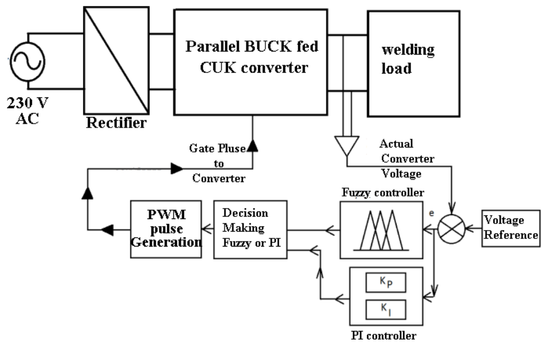


Figure 8. Proposed Adaptive hybrid system

4.Experimental detail of Fuzzy Logic Controller

Fuzzy controllers developed based ability to under- stand the behavior of Converter. The two inputs for the fuzzy controller form the CUK converters output voltage. The first input is the error in the difference between reference output voltage VR with current output voltage (VP). The second input is change in error, the difference between two successive errors and is given by,

$$e\,|k| = VR - VP \tag{14}$$

$$Ce\,|k| = e\,|k| - e\,|k-1| \tag{15}$$

The first step in the design of a fuzzy logic controller is to define membership functions for the inputs. Seven fuzzy levels or sets are chosen and defined by the following library of fuzzy-set values for the error e and change in error Ce.

A typical rule can be written as follows. If e is NB and de is PS then output is ZE where the labels of linguistic variables of error (e) are, change of error (de) and output respectively, de and output represent degree of membership.

Table 1. Fuzzy rule base

e\de	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	ZS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. Result and Discussion

MATLAB software is used to check the Performance analysis of all three type of multi phasing topology(BUCK fed BUCK, BUCK fed SEPIC and BUCK fed CUK) on closed loop with PI controller. The performance of BUCK fed CUK converter is better than other topology which is shown in table.2, thus proposed converters is simulated in closed loop with PI, fuzzy and Adaptive hybrid systems is proposed. Figure 9. Shows output voltage waveform of converter operated under open loop. The point 'a' shows the instant at which load is applied and the disturbance in waveform that is voltage drop to zero. At point 'b' (15sec) change in load there is a drop in voltage is12V,steady state error is 3V.

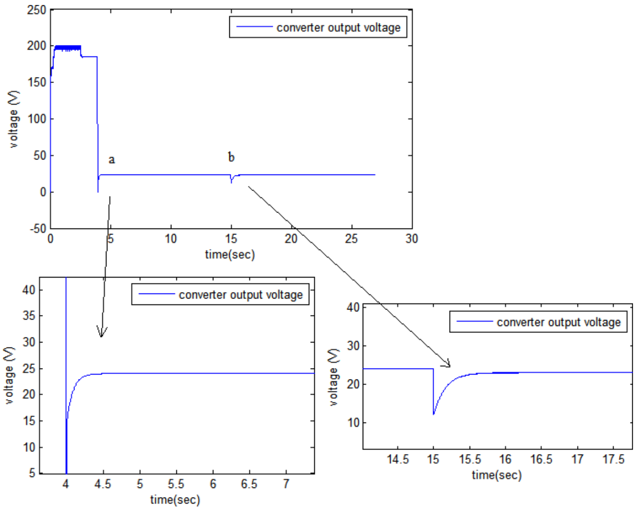


Figure 9. Open loop output voltage

The closed loop current response and voltage response with various controllers is depicted in Figure.10 and Figure.11 respectively. The characteristics are analyzed with respect to the points 'a', 'b', 'c', d' and are tabulated in table.3 which clearly figure outs the dynamic of the system with different controller. From the simulation it is understood that the proposed Adaptive controller is robust and has better steady state and fast dynamic response which is the requirement in DC welding application.

Table 2. Performance analysis of various converter topology

Parameter	BUCK fed BUCK	BUCK fed SEPIC	BUCK fed CUK
Rise time (sec)	0.036	0.022	0.01
Voltage ripple (V)	0.75	1.1	0.4
Current ripple (A)	3.2	4.3	1.3
Peak over shoot (V)	690	890	610

6. Experimental Analysis

The Hardware setup of BUCK fed CUK converter is shown in Figure12. Hybrid algorithm is implemented using PIC16F877A micro controller from microchip. The Voltage output from converter is taken as feedback and given to micro controller through port A, with the code return in pulses are generated which is shown in Figure13. The output voltage and current are scaled down version of simulations.

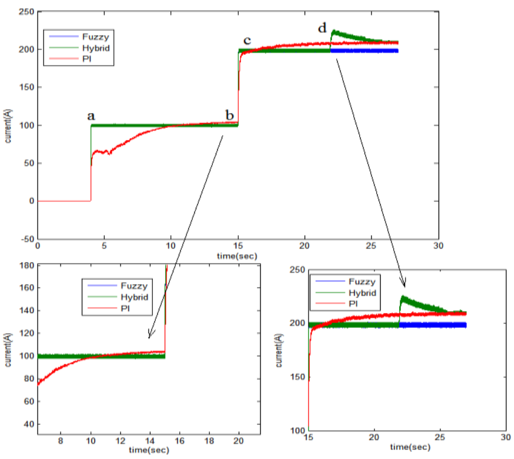


Figure10. Various Controller Current waveform

Hardware model is designed for 1.4A which is shared by parallel converter as 0.7A. Input Voltage from diode rectifier of 45.6 V is passed to filter is given as converter input shown in Figure.14, output current waveform of converter is shown in Figure.15.

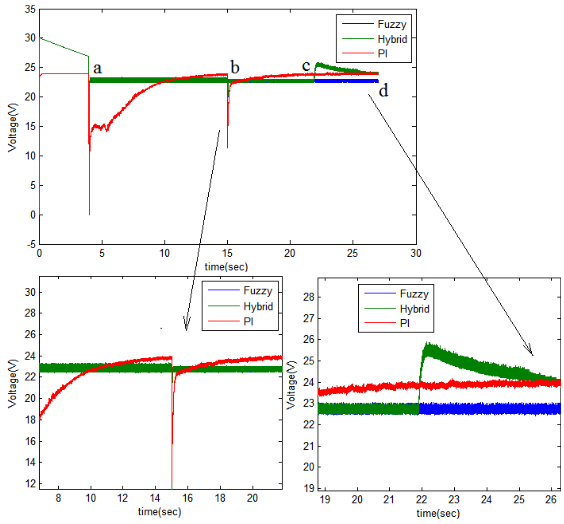


Figure 11. Various controller output voltage waveform

Table 3. Controller performance

Parameter	PI-Controller	FUZZY controller	Adaptive controller
Out put current Rise time(sec)	0.2	0.5	0.4
Steady State Current value(A)	208	198.5	210.5
Steady State Voltage value(V)	23.9	22.75	24
Output Current ripple (A)	3	5	2.5
Output Voltage ripple (V)	0.3	0.5	0.25

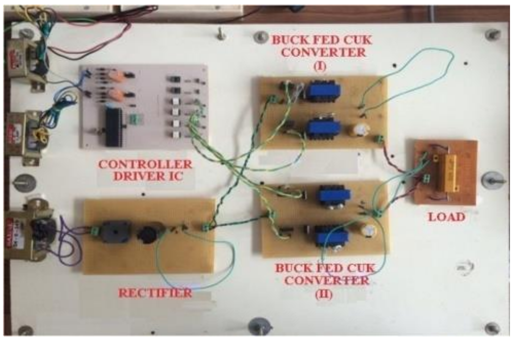


Figure 12. Complete hardware setup

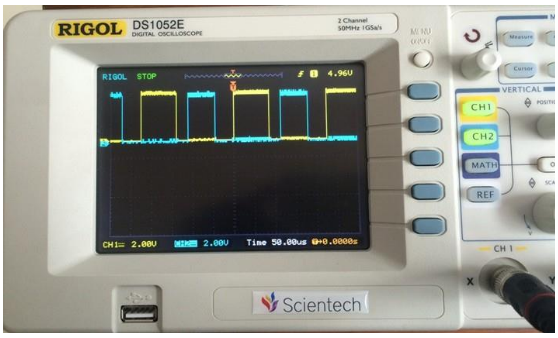


Figure 13. Pulse pattern to power circuit

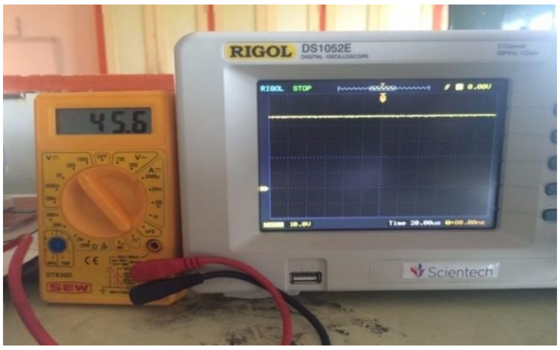


Figure 14. Input voltage

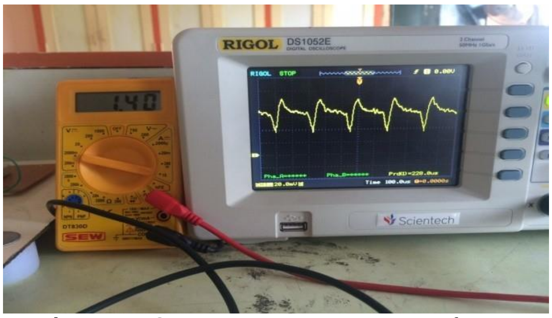


Figure 15. Converter output current waveform

7. Conclusions

This paper proposes a Adaptive controller for parallel multi phasing BUCK fed CUK converter for DC welding applications.

The Adaptive hybrid algorithm combines the merits of Conventional controller and fuzzy controller. The simulation results indicate the robustness of the controller. Hardware results validate the proposed controller for Parallel converter and justifies its application for welding application.

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